DOWNSTREAM PROCESSING

Problem Set #4

Problem 1

Streptomycin is an antibiotic used in combination with other drugs to treat tuberculosis (TB), which is a chronic bacterial infection. Suppose that you are running a fungal fermentation to produce this antibiotic and that the biomass titer at harvest is 20 g/L. To separate the biomass from the streptomycin product, you will harvest the fermentation broth, add filter aid to a concentration of 150 g/L, and proceed to perform the primary separation using a rotary vacuum filter.

In pilot studies using a filter having 1.5 m^2 area, the pressure drop across the filter is 12 psi and the data shown in Table 1 are collected.

Table 1: Filtration Time and Volume of Filtrate Collected

Filtration Time (min)	Total Volume Collected (L)
3	5.0
28	20.0
293	65.0
375	75.0
512	85.0

The viscosity of the filtrate is 2.69 x 10^{-4} lb/ft-s and the cake is compressible with a resistance (R_c) that can be expressed as follows:

$$R_c = \alpha \rho_o \left(\frac{V}{A} \right)$$

where α = specific cake resistance (length/mass)

ρ_o = mass of cake solids per volume of filtrate

V = filtrate volume

A = filter area

a) Derive an equation that relates area (A), time (t), and volume (V) to area and volume in the following functional form (f means function of):

$$\frac{At}{V} = f\left(\frac{V}{A}\right)$$

b) Use your answer from part a to determine the value of α (in units of ft/lb) and the filter resistance R_m (in units of ft^{-1}).

c) If you are to scale up this operation to filter 10 m^3 of fermentation broth in 10 hours and the maximum filter area per rotary vacuum filter machine is 80 m^2, how many machines must be used in parallel?

Problem 2

A tubular membrane is being used for ultrafiltration of cheese whey. In the absence of protein, the membrane has a filtration of 100 L/m^2-hr when the transmembrane pressure is 0.4 atm. The whey proteins have an average diffusivity of 4 x 10^{-7} cm^2/s, and the osmotic pressure in atmospheres is given by Jonsson's equation[1]:

$$\pi = (4.4 \times 10^{-3})C - (1.7 \times 10^{-6})C^2 + (7.9 \times 10^{-8})C^3$$

where C is the protein concentration in grams per liter. Based on the channel geometry, flow conditions, and whey diffusivity, the protein mass transfer coefficient, k, is 7.8 x 10^{-4} cm/s.

a) Calculate the phenomenological hydraulic permeability, L_P, for the transport of water across the membrane.

b) Calculate the effect of ΔP on the membrane flux if the protein concentration is 10 g/L. Please show the effect by creating a plot of flux (L/m^2-hr) vs. ΔP (atm) for fluxes ranging from 10 to 104 L/m^2-hr. You may assume that protein is completely rejected from the membrane. (*Hint: this problem should be done using Excel*)

[1] Jonsson, G., *Desalination*, **51**:61 (1984)

Problem 3

In Problem 2 you determined the effect of ΔP on ultrafiltration membrane flux for cheese whey being filtered at a concentration of 10 g/L. In this problem your objective is to analyze the effect of bulk protein concentration on membrane flux.

If the calculations performed in Problem 2 were done for several protein concentrations, the following type of plot could be generated[2]:

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Please see:
Tutunjian, R. S. "Ultrafiltration Processes in Biotechnology." In *Comprehensive Biotechnology*. Vol. 2, *The Principles of Biotechnology: Engineering Considerations*. Edited by C. L. Cooney, and A. E. Humphrey. Elmsford, NY: Pergamon Press Ltd., 1985, p. 417. ISBN 0-08-032510

As shown in the figure above, at a specific transmembrane pressure a different flux is obtained for each bulk protein concentration. In the region in which flux is independent of transmembrane pressure, a gel layer exists that limits the maximum flux that can be achieved.

The data in Table 2 were collected from the ultrafiltration of a protein at several different concentrations when the flux was pressure independent.

Table 2: Ultrafiltration Flux as a Function of Bulk Protein Concentration

Bulk Protein Concentration (g/L)	Filtration Flux (L/m^2-hr)
10	103.8
100	39.5
200	20.0
300	8.8

[2] Tutunjian, R.S., *Ultrafiltration Processes in Biotechnology*, in *Comprehensive Biotechnology*, Vol. 2 The Principles of Biotechnology: Engineering Considerations, C.L. Cooney and A.E. Humphrey, Editors. 1985, Pergamon Press Ltd.: Elmsford, NY. p. 417. ISBN 0-08-032510

a) Please use the data in Table 2 to calculate the gel layer concentration, C_g.

b) What is the maximum filtration flux that can be achieved by increasing pressure for whey protein being filtered at a concentration of 20 g/L? Please use the data for the filtration of cheese whey in Problem 2 to help answer this question.

Problem 4

A large-volume application of membranes is ultrafiltration in the dairy industry in which milk is preconcentrated for the manufacture of soft cheeses: mozzarella, camembert, brie, fetta, and cottage cheeses. You are consulting for a cheese manufacturer that is performing ultrafiltration of milk at 50 °C. The data available for the membrane used in the process are as follows:

Hydraulic Channel Diameter (d_h)	=	0.11 cm
Channel Length (L)	=	63.5 cm

The physical properties of milk are as follows:

Liquid Density	=	1.03 g/cm^3
Liquid Viscosity	=	0.008 g/cm-sec
Protein Diffusivity (D)	=	7.0 x 10^{-7} cm^2/second
Bulk Protein Conc. (C_b)	=	3.1%
Gel Protein Conc. (C_g)	=	22%

It has been found that it takes 24.7 minutes to process 1,000 L of milk using 100 m^2 of membrane when the fluid velocity is maintained at 100 cm/s and the filtration flux is pressure independent. If rescheduling of the process requires that 1,000 L of milk be processed in 60 minutes by only changing the channel fluid velocity, what must the new velocity be? (Hint: Laminar flow in the filtration apparatus occurs for Reynolds numbers below ~ 2,300).